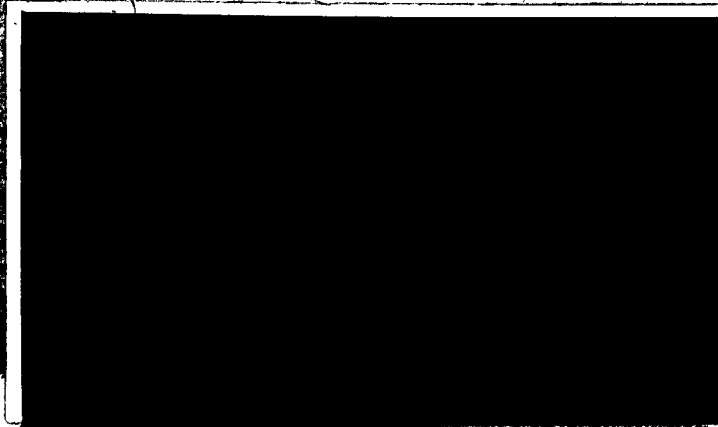


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PROGRESS REPORT NO. 2

ON

CONTRACT NObs-88181

1 JANUARY - 31 MARCH 1963

31 March 1963

Copy No. 10

Sponsor: Department of the Navy, Bureau of Ships  
Applied Research Division Ship Silencing Branch

Project S-F-013-11-01, Task 1359

DEFENSE RESEARCH LABORATORY  
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AUSTIN 12, TEXAS

### ABSTRACT

Printing and binding work on the acoustic filter design manual, prepared under Contract NObs-86165, has been completed and copies have been mailed to activities designated on the initial distribution supplied by the Bureau of Ships. Additional copies are on hand at this Laboratory. Construction of the automatic plotting impedance computer is approximately 80% complete. Progress in making admittance measurement for use in filter calculations has been slowed because of an apparent change in characteristics of the acoustic impedance head. This change was discovered while measuring the impedance of a unit built to offer a predominantly resistive impedance equal to the characteristic impedance of water-filled copper nickel pipe of 2.73-in. inside diameter. The measurements indicated that the unit exhibited the desired impedance magnitude of  $+70 \text{ dB re } 1 \text{ gm/sec cm}^4$  at only two frequencies in the range  $25 \leq f \leq 2500 \text{ cps}$ ; these were near 37 cps and 1200 cps. However, since the impedance head may not have been operating properly when these data were taken, the results obtained may be invalid. Sound transmission characteristics of piping system and filter elements are discussed from the acoustic admittance parameter standpoint.

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PROGRESS REPORT NO. 2  
ON  
CONTRACT NObs-88181

I. ADMINISTRATION

A. Introduction

This report covers technical work performed under Contract NObs-88181 during the months of January, February, and March, 1963.

On 25 February 1963 Dr. E. L. Hixson visited the Bureau of Ships, Code 345, and conferred with Dr. R. M. Sherwood on technical work being performed under this contract.

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B. Research Staff

<u>Name</u>	<u>Degree</u>	<u>Position</u>	<u>Time</u>
Cousins, E. L.	B.S.	Research Engineer	1.00
Galloway, D. G.*	B.S.	Research Engineer	0.50
Hixson, E..L.	Ph.D.	Research Engineer	0.38
Kahlbau, J. V.	M.A.	Supervisor, Noise and Vibration Section	1.00
McKinney, C. M.	Ph.D.	Head, Acoustics Division	0.05

\*Terminated 31 January 1963

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## II. SUMMARY OF TECHNICAL WORK

### A. Acoustic Filter Design Manual

The filter design manual, Guide to the Selection of Acoustic Filters for Liquid-Filled Systems, written under Contract NObs-86165, has been completed. Copies of this report were mailed on 29 March 1963, to activities specified by the Bureau of Ships.

Six hundred and seventy-nine (679) copies are still on hand to fill requests as may be authorized by the Bureau of Ships.

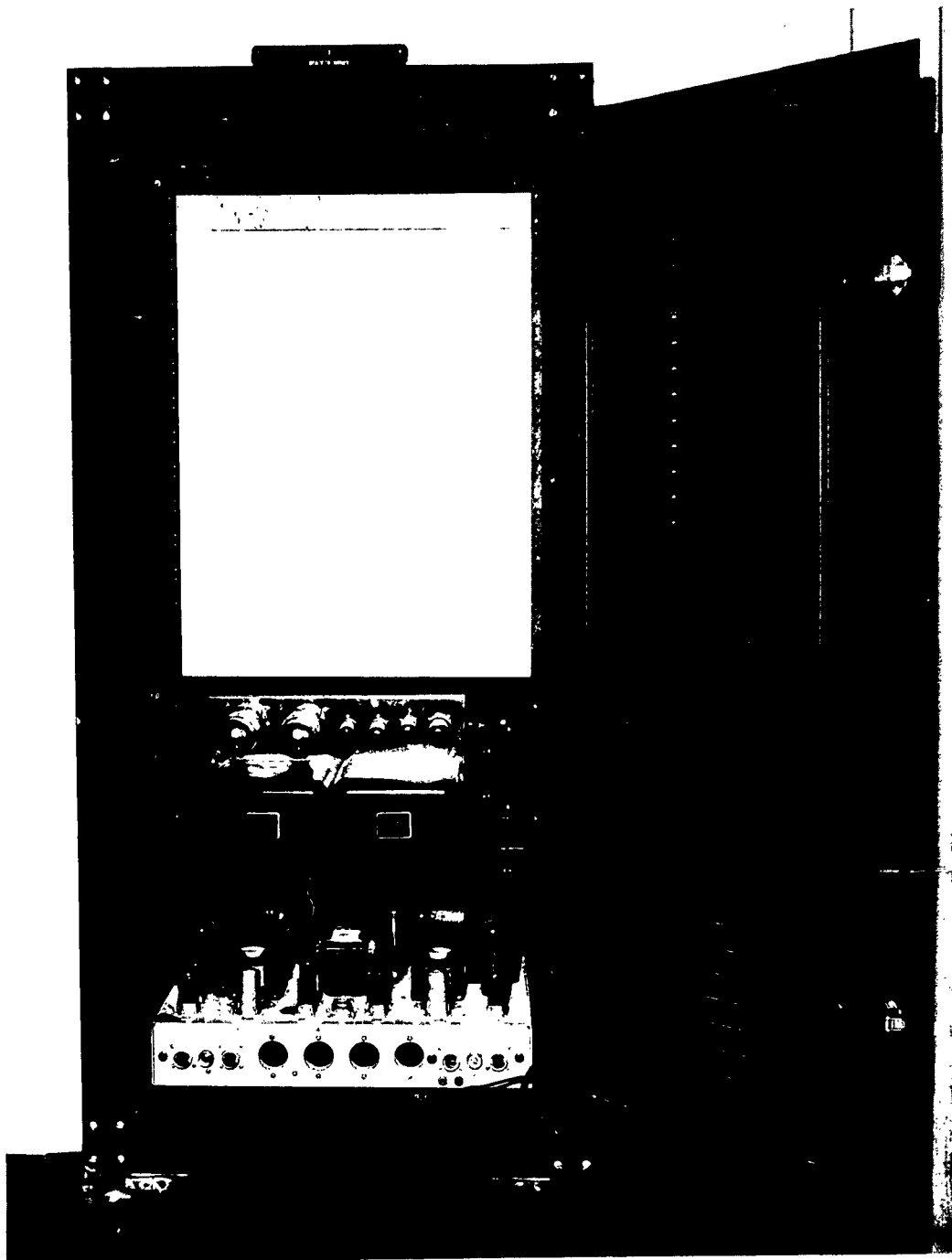
## B. Impedance Computer

Parts for the impedance analog computer are under construction. The main assembly is to be mounted in a 47-1/2 x 22 x 17-in. rack supported on casters. Subassemblies of this unit will be (1) the main power supply, (2) power amplifier, (3) signal preamplifiers, and (4) the control and signal processing chassis. The master oscillator, phase meter, plotter, and impedance head will be separate units.

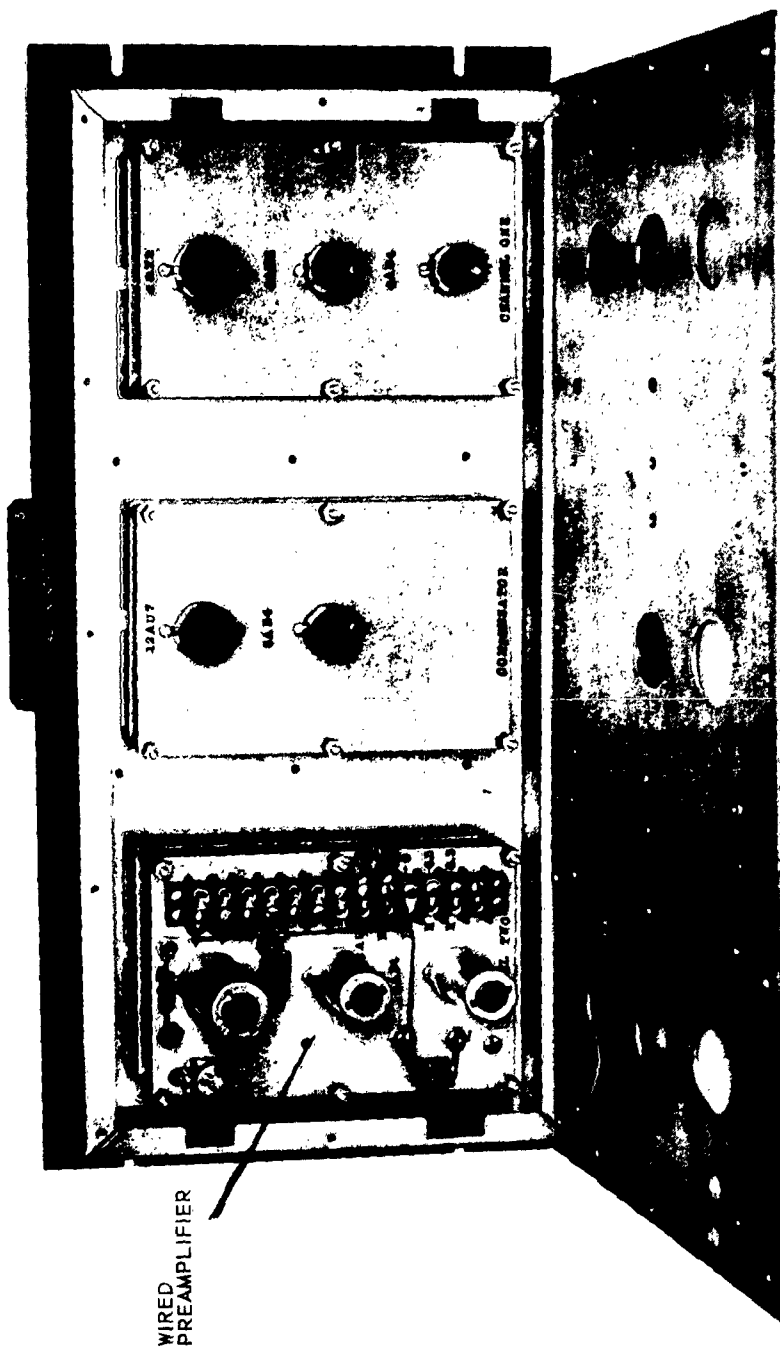
Photograph 88181-5 shows the main assembly rack with the power supply and power amplifier in place. Other units to be placed in this enclosure are approximately 80% complete, as shown in Photographs 88181-6 and 88181-7; these are respectively the signal preamplifiers and control panel. An auxiliary input jack has been provided on the control panel to simplify use of the computer for measuring transfer impedances and admittances.

Two of the units of the computer external to the main rack, the phase meter and plotter, are pieces of commercial equipment. The impedance head is an assembly of a small magnetic shaker with acceleration and pressure transducers; it was on hand and in general use before construction of this computer was begun. The master oscillator is a commercial unit modified by the addition of a nonlinear mechanical drive. The purpose of this modification is to render the shaft position versus frequency characteristic of the oscillator logarithmic over the range 10-20,000 cps. Photograph 88181-8 shows a rear view of the oscillator with the drive unit in place.

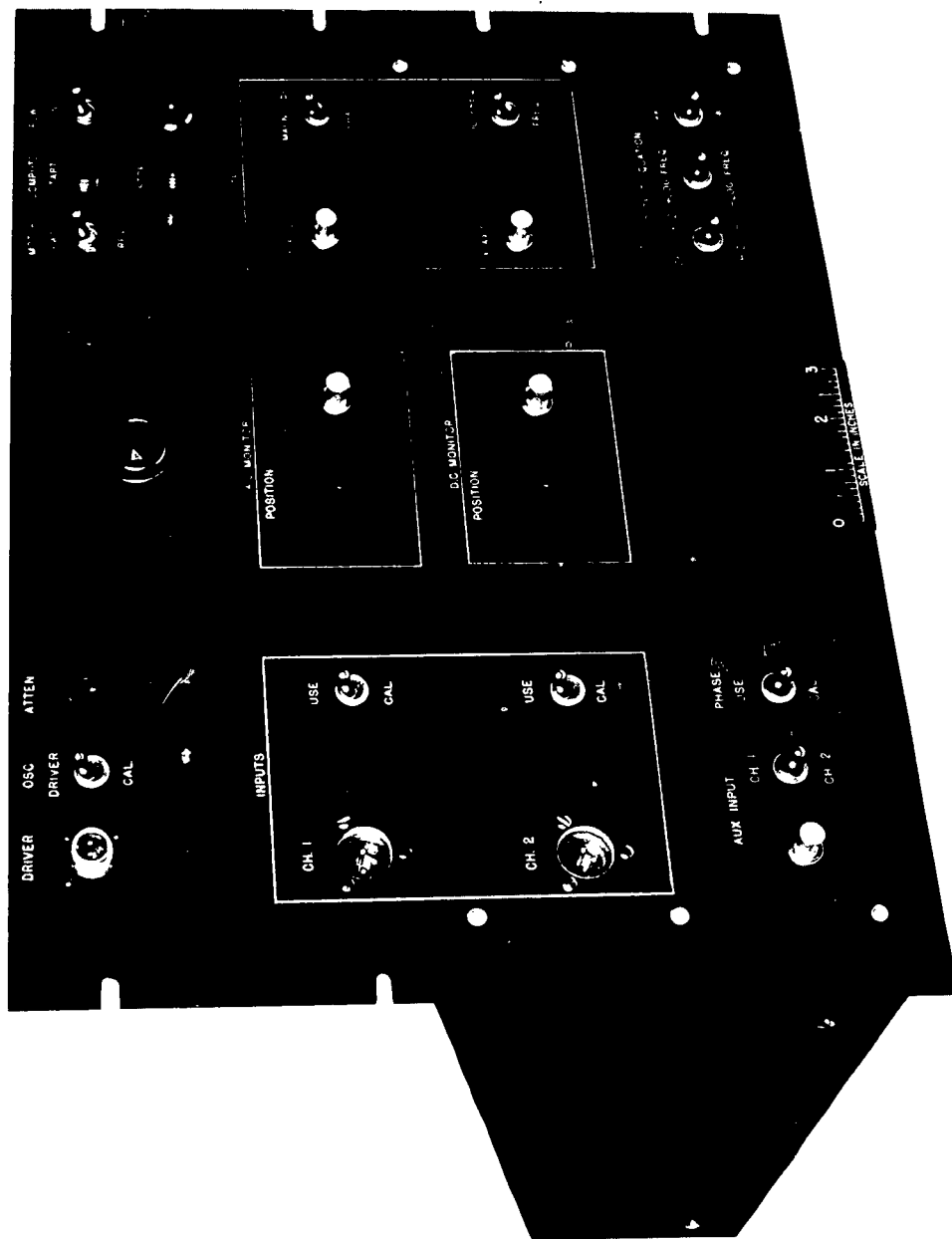




COMPUTER MAIN ASSEMBLY RACK



SIGNAL PREAMPLIFIER ASSEMBLY



IMPEDANCE PLOTTING COMPUTER CONTROL PANEL



MECHANICAL DRIVE UNIT MOUNTED  
ON BEAT FREQUENCY OSCILLATOR

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C. Filter Calculations with Measured Admittances

In Progress Report No. 1, steps for investigating a particular combination of acoustic filter, source, and load were described. The investigation entailed measurements of acoustic admittances of the filter branch element, the load, and the source. Progress in making the needed measurements has been retarded by erratic behavior of the impedance head. Difficulties with this unit are discussed in the following section of this report.

The computer program for calculating the filter output-input sound pressure ratio magnitude, however, has been completed and checked using assumed admittance values.

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#### D. Resistive Acoustic Termination

Work toward devising a simple means of terminating water-filled copper-nickel pipe, in an acoustic impedance predominantly resistive over at least a limited frequency range, has been continued. The liquid flow resistance unit, previously reported<sup>1</sup>, has been assembled and subjected to some acoustic impedance measurements.

The resistance unit was coupled to the impedance measuring head through a length of water-filled pipe (Dwg. AS-7834). On the basis of previous measurements<sup>2</sup> the characteristic impedance of water-filled pipe of this type is taken as 70 dB re 1 gm/sec cm<sup>4</sup>. For any frequencies at which the impedance of the termination unit is real and equal to this value, the input impedance at the point of attachment of the measuring head should also assume this value. One test run produced the impedance magnitude curve shown in Dwg. AS-7835. It is noted that the desired condition with regard to impedance magnitudes is indicated at only two frequencies, 44 and 600 cps; data for an open-end water column are also given for purposes of comparison.

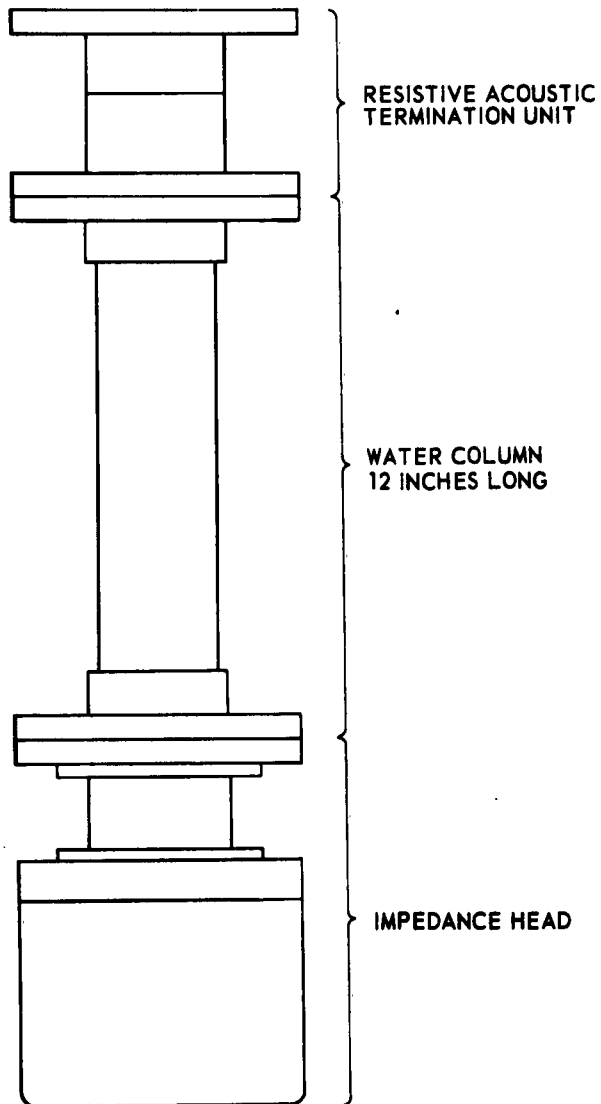
Further impedance measurements were made on the resistance unit. It was coupled directly to the impedance head as shown in Dwg. AS-7836. Curves 1 and 2, Dwg. AS-7837, were plotted from measurement runs made on two different days. Results of the two runs are in close agreement over the entire range of measurement.

The resistance unit was then disassembled from the top and the input impedance was measured after each part was removed. Curves 1-6, Dwg. AS-7838, show impedance magnitude vs. frequency for the top rubber diaphragm removed, the silicon fluid level lowered to the top of the perforated plate, the fluid level lowered to the bottom of the perforated plate, the plate removed, all

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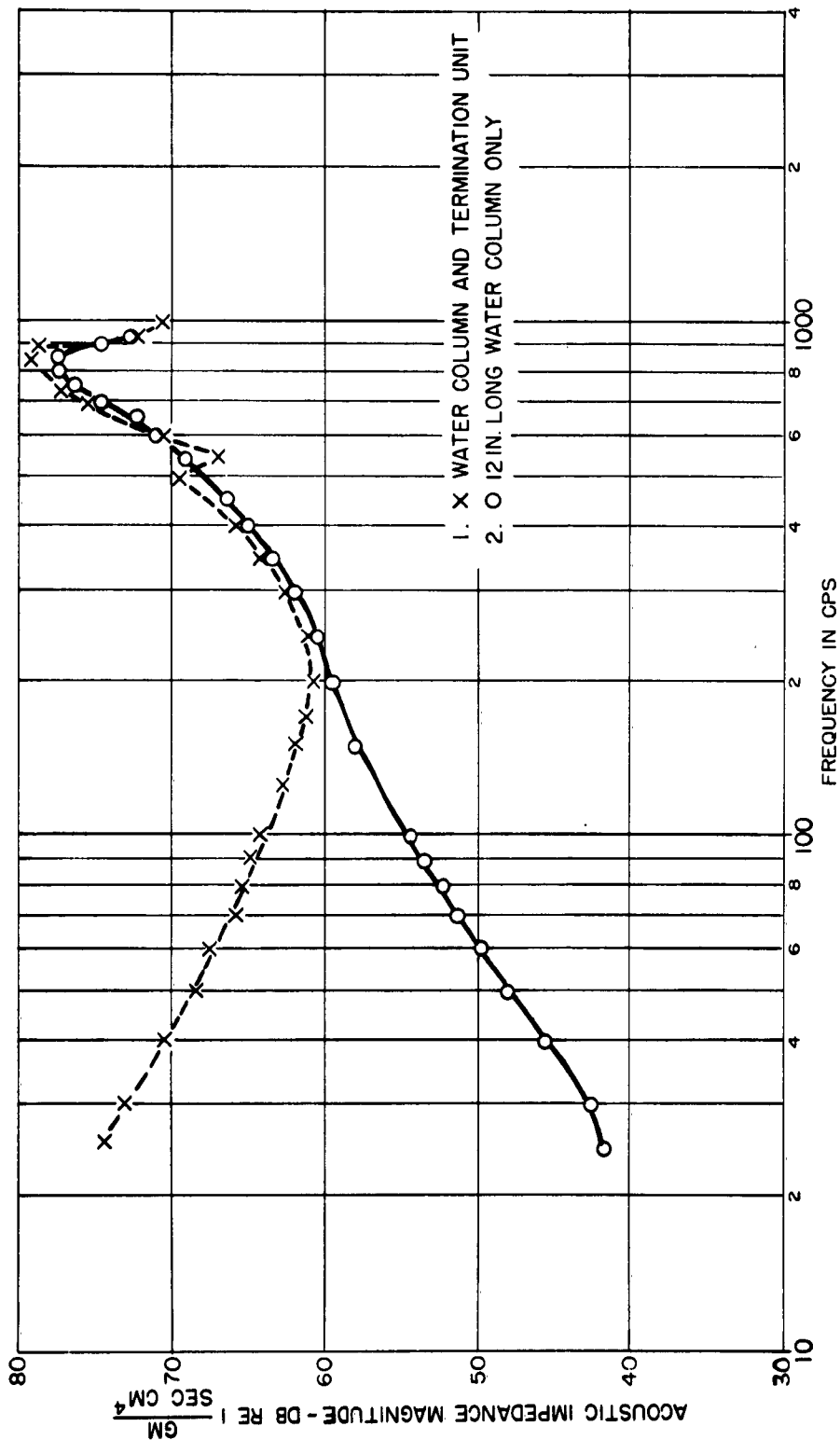
<sup>1</sup>Progress Report No. 1 on Contract NObs-88181, Defense Research Laboratory, The University of Texas, 1 October - 31 December 1962, p. 12.

<sup>2</sup>Progress Report No. 20 on Contract NObs-77033, Defense Research Laboratory, The University of Texas, 1 July - 30 September 1961, p. 10.

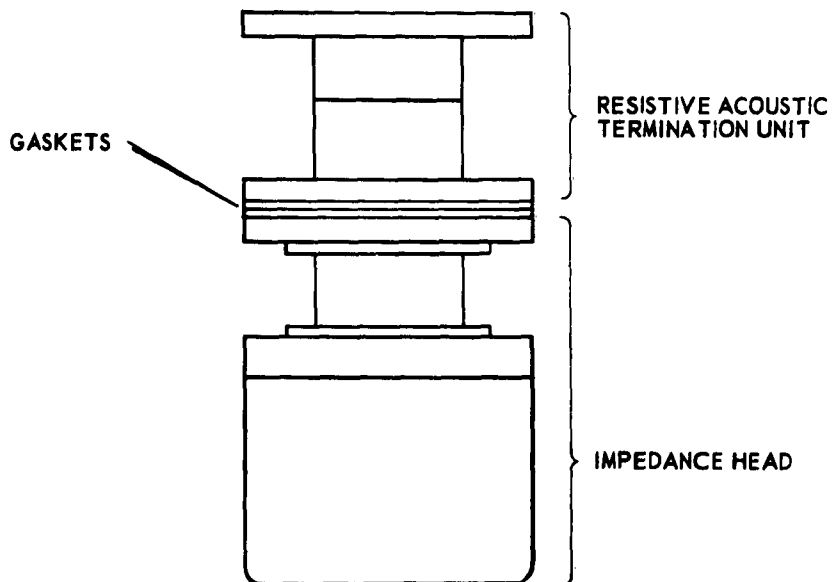


**ARRANGEMENT OF IMPEDANCE HEAD,  
WATER COLUMN, AND TERMINATION UNIT**

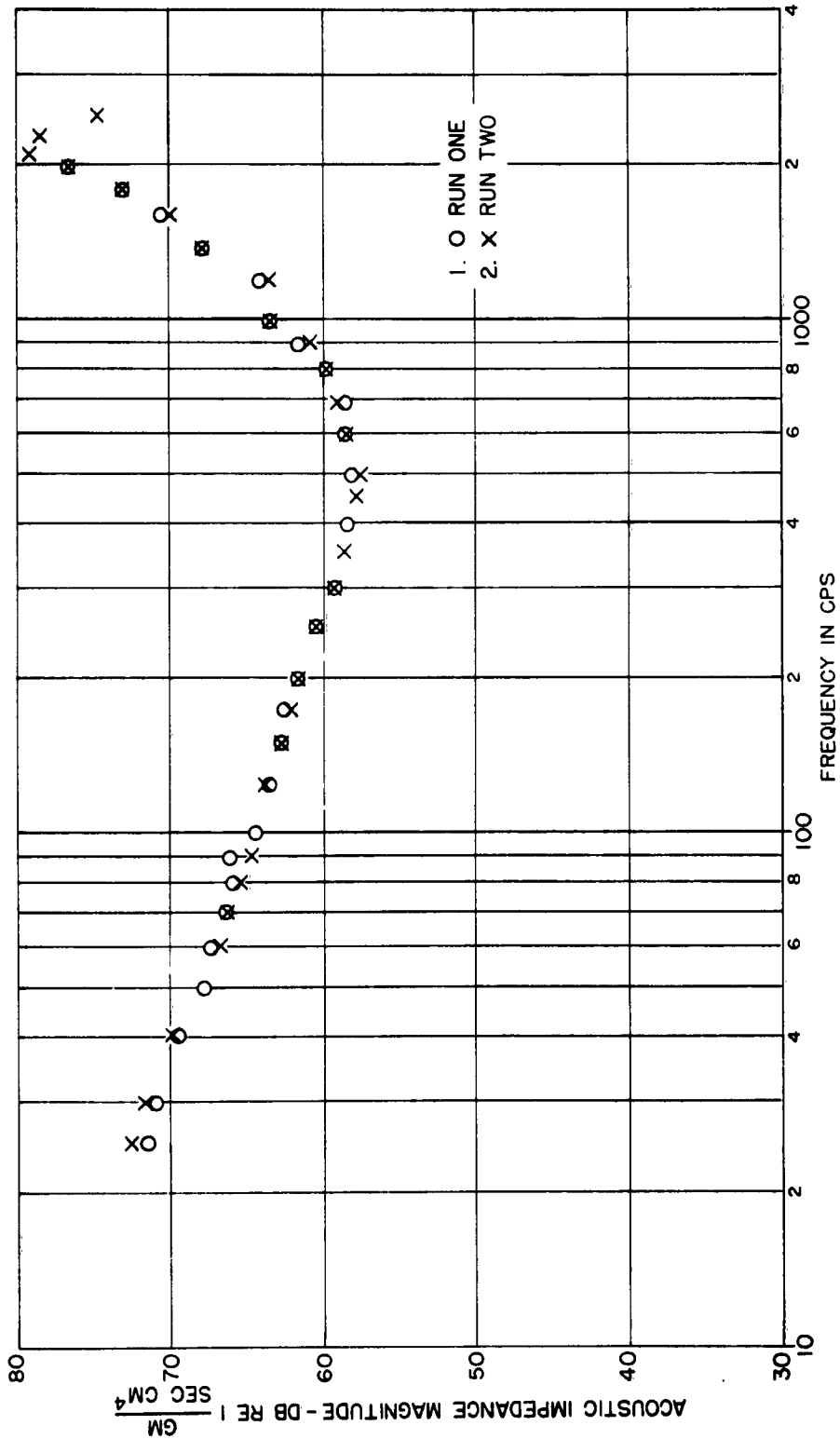
# INPUT ACOUSTIC IMPEDANCE MAGNITUDE VS FREQUENCY



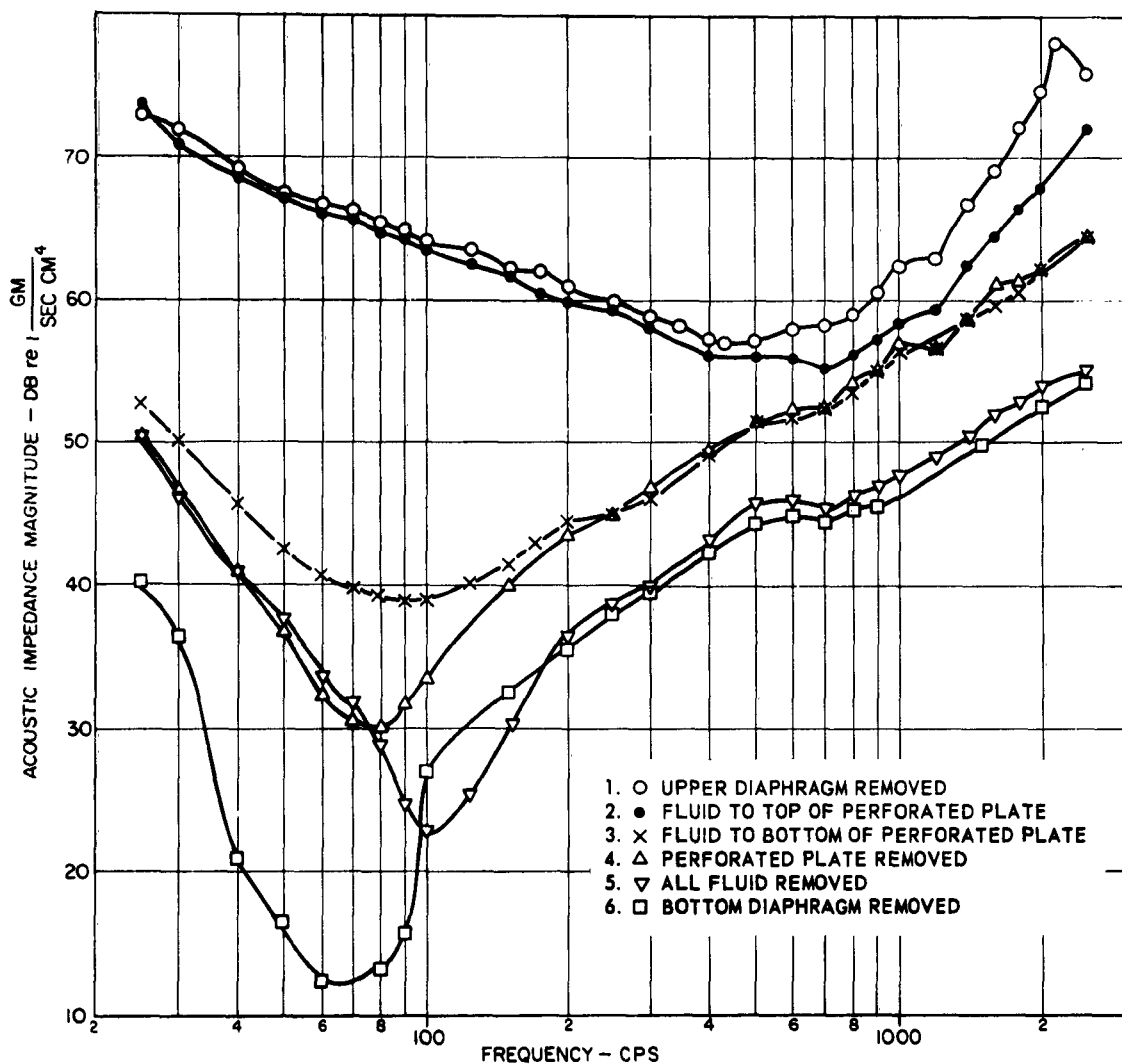




**IMPEDANCE HEAD AND TERMINATION UNIT DIRECTLY COUPLED**



RESISTIVE TERMINATION UNIT  
ACOUSTIC IMPEDANCE MAGNITUDE VS FREQUENCY



IMPEDANCE OF TERMINATION UNIT  
FOR VARIOUS STAGES OF DISASSEMBLY

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the fluid removed, and finally even the bottom diaphragm removed. All these curves appear credible except the one for the impedance head alone; it has an unusual shape for frequencies below 200 cps. The impedance head would be expected to exhibit an almost pure inertance, so the impedance should change with a uniform, positive slope of 20 dB per decade. These unexpected results led to checking the instruments by repeating measurements previously made on 13-in. water columns. The recently obtained results are plotted along with the older data on Dwg. AS-7839. Comparison of these and similar curves indicate a change in low frequency characteristics of the impedance head. The unit was disassembled and inspected. No cause for the apparent changes in characteristics was found. The accelerometer was recalibrated; its sensitivity was found unchanged. The hydrophone was checked by a low-frequency calibration technique reported by Schloss and Strasberg.<sup>3</sup> A sensitivity of -116 dB re 1 volt/ $\mu$ bar was found; this agrees with previously obtained values within 1 dB.

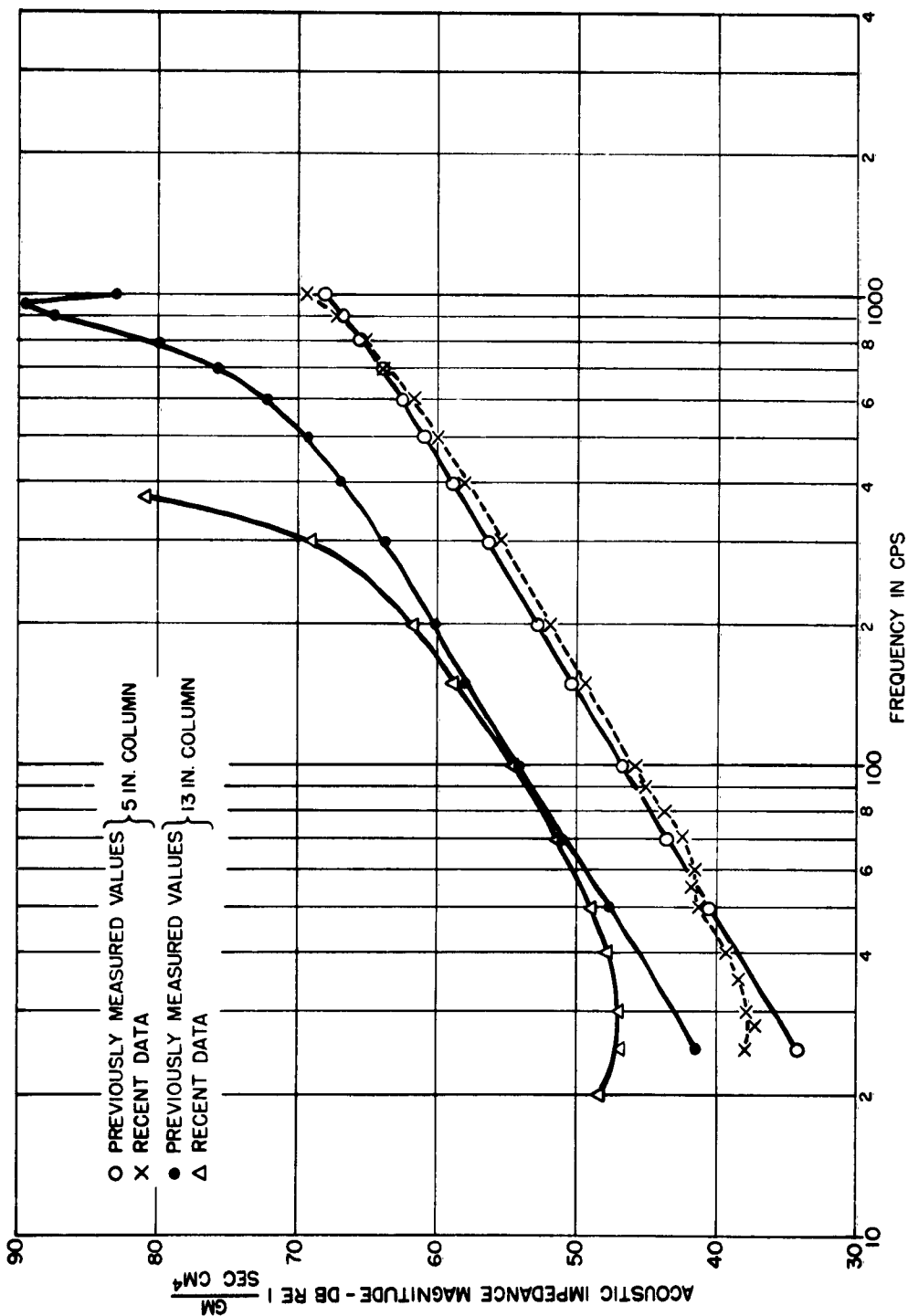
Another check of the hydrophone calibration was made by a related method. Acoustic impedance of a water column above the hydrophone was measured by two different methods, one utilizing the hydrophone signal, the other only signals from a mechanical impedance head. Details of the experimental arrangement are shown in Dwg. AS-7840. A column of water contained in a metal pipe in which the hydrophone was suspended was driven from below through a mechanical impedance head by a magnetic shaker. Electrical compensation was made for the mass of the pipe and the water below the center of the hydrophone. Thus the mechanical impedance of only the column of water above the hydrophone  $Z_m$  was measured. This value of  $Z_m$  was divided by the square of the column section area  $S$  to give acoustic impedance  $Z_\alpha$ .

$$Z_\alpha = \frac{Z_m}{S^2} .$$

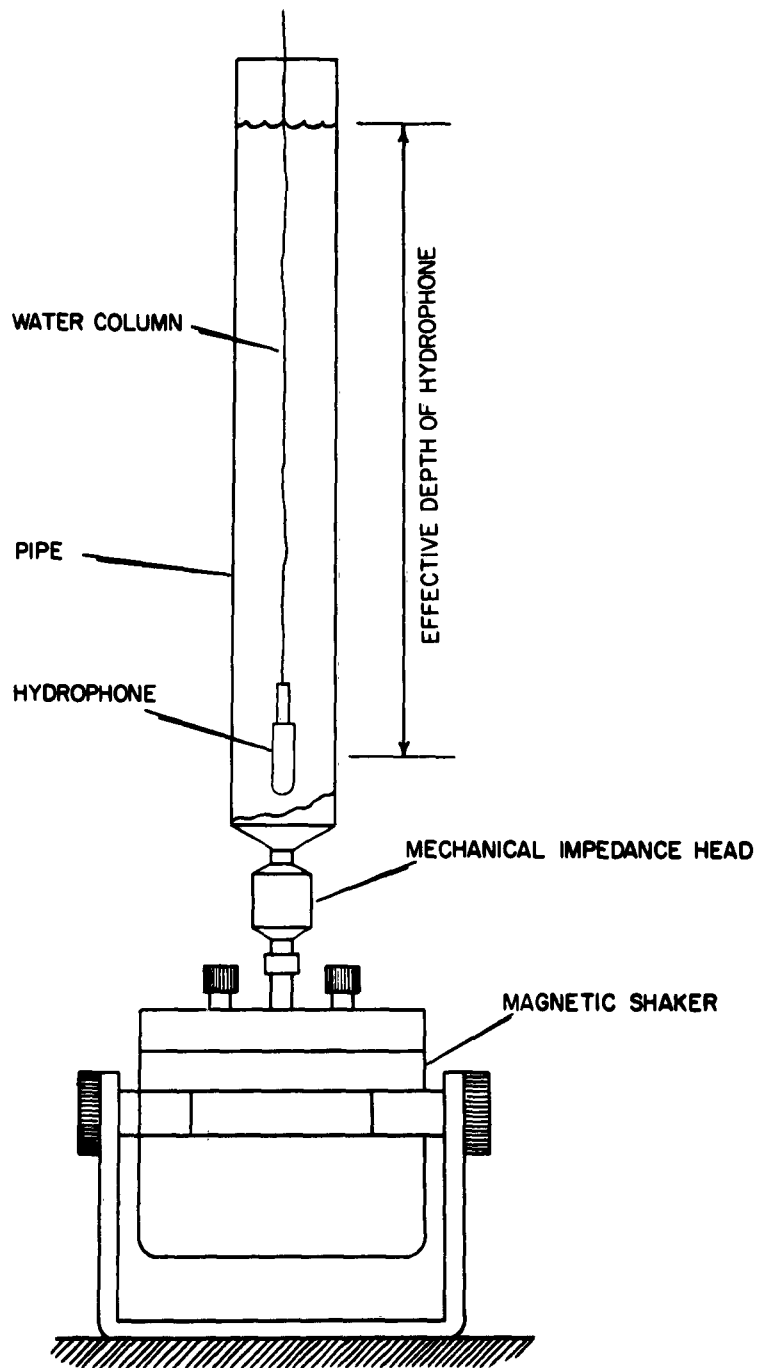
Values of  $Z_\alpha$  measured in this way are compared with calculated values and values

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<sup>3</sup>F. Schloss and M. Strasberg, "Hydrophone Calibration in a Vibrating Column of Liquid," The Journal of the Acoustical Society of America 34, No. 7, pp. 958-960 (1962).



OPEN END WATER COLUMN  
ACOUSTIC IMPEDANCE MAGNITUDE VS FREQUENCY

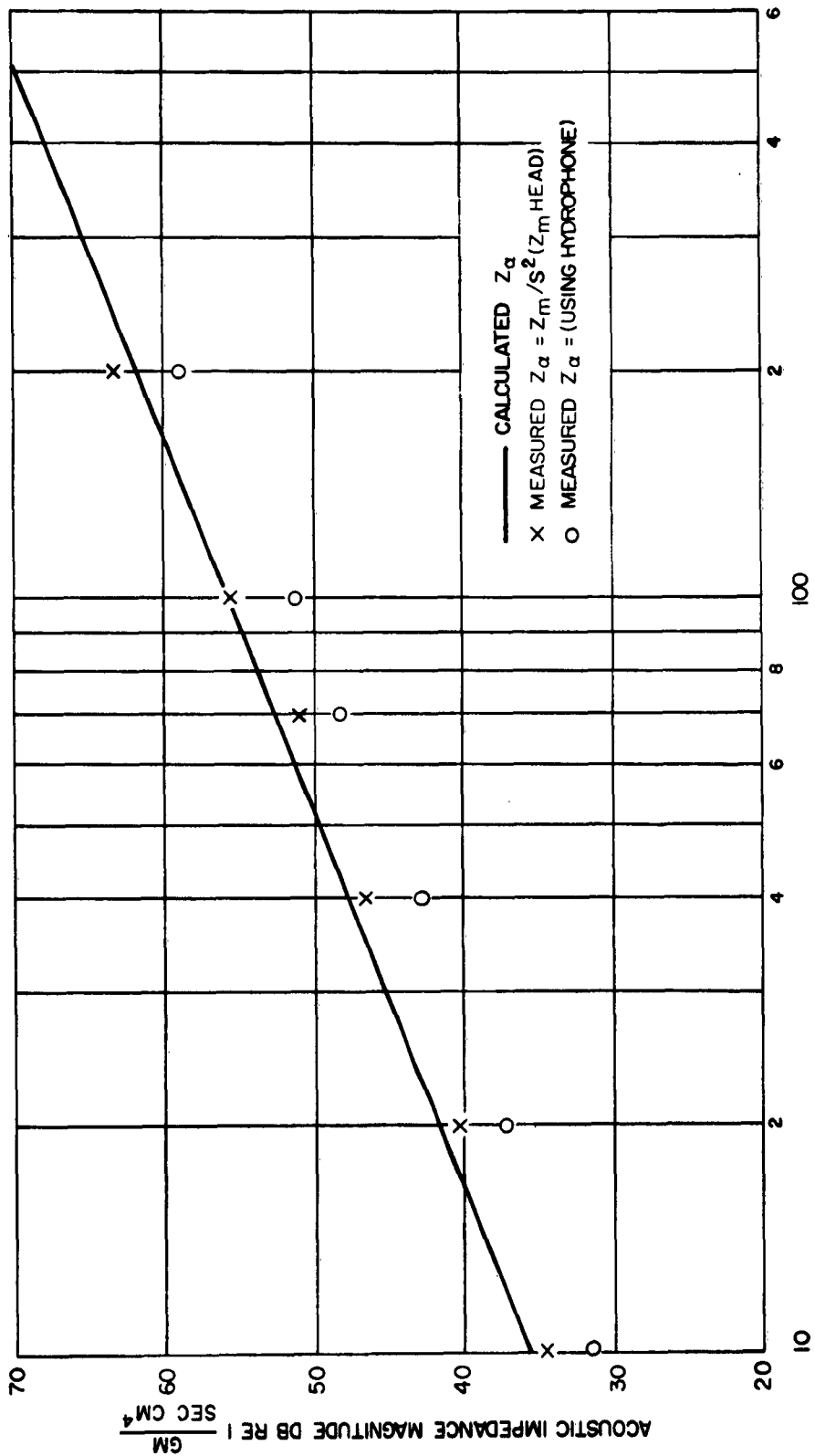


SETUP FOR LOW FREQUENCY CALIBRATION OF HYDROPHONE  
BY MECHANICAL IMPEDANCE MEASUREMENT

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found using the hydrophone and mechanical impedance head accelerometer signals, Dwg. AS-7847. It is seen that slopes of the three sets of data are in close agreement in the frequency range 10-200 cps. The displacement of the curve obtained using the hydrophone signal by approximately -3 dB suggests that the hydrophone may have lost sensitivity. However, such a loss does not explain the peculiar low frequency characteristics of the impedance head, the cause of which remains an unresolved question.



IMPEDANCE MEASUREMENTS ON 14 INCH WATER COLUMN



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### E. Sound Transmission Characteristics of Piping System and Filter Elements

The acoustical transmission characteristics of piping system components such as valves, bends, "tees", manifolds, etc., are not readily calculated from theoretical considerations. However, certain characteristics of these elements can be measured which allow the calculation of the ratio of sound pressure levels across the element and the admittance presented by it. Acoustic filter calculation methods can then be used to determine the transmission loss from the input to any part of a piping system. With a known sound pressure level at the input, the levels at various places in the system may be determined.

Any section of pipe that contains a valve, bend, strainer plate, or other discontinuity can be considered a two-port element. If the acoustic pressures at and the volume velocities into each port are considered, a set of two port equations may be written:

$$\begin{aligned} P_1 &= Z_{11} \bar{V}_1 + Z_{12} \bar{V}_2 , \\ P_2 &= Z_{21} \bar{V}_1 + Z_{22} \bar{V}_2 . \end{aligned} \tag{1}$$

Here subscripts "1" refer to port 1 and subscripts "2" refer to port 2. The "Z" parameters are measurable quantities defined as follows:

$$\begin{aligned} Z_{11} &= \left. \frac{P_1}{\bar{V}_1} \right|_{\bar{V}_2 = 0} , \text{ the input impedance at port 1 with} \\ &\quad \text{port 2 blocked;} \\ Z_{21} &= \left. \frac{P_2}{\bar{V}_1} \right|_{\bar{V}_2 = 0} , \text{ the transfer impedance between ports} \\ &\quad \text{2 and 1 with port 2 blocked;} \end{aligned}$$

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$$Z_{22} = \left. \frac{P_2}{\bar{V}_2} \right|_{\bar{V}_1 = 0}, \text{ the input impedance at port 2 with port 1 blocked; and}$$

$$Z_{12} = \left. \frac{P_1}{\bar{V}_2} \right|_{\bar{V}_1 = 0}, \text{ the transfer impedance between ports 1 and 2 with port 1 blocked.}$$

These parameters can be measured with an acoustic impedance device at one port and a hydrophone at the blocked port.

If the pressure  $P_1$  at port 1 is known and port 2 is terminated in some impedance  $Z_l$ , equations (1) become

$$P_1 = Z_{11} \bar{V}_1 + Z_{12} \bar{V}_2$$

$$0 = Z_{21} \bar{V}_1 + (Z_{22} + Z_l) \bar{V}_2 \quad (2)$$

where

$$P_2 = -Z_l \bar{V}_2.$$

From equations (2) the transfer function becomes

$$\frac{P_2}{P_1} = \frac{Z_l Z_{21}}{Z_{11} (Z_{22} + Z_l) - Z_{12} Z_{21}}. \quad (3)$$

The input impedance is then

$$Z_{in} = Z_{11} - \frac{Z_{12} Z_{21}}{Z_{22} + Z_l}. \quad (4)$$

This is then an impedance transformation equation that relates  $Z_{in}$  to  $Z_l$ . Admittance methods are more convenient than impedance for acoustic filter

calculations.<sup>4</sup> Equation (4) can be expressed as an admittance transformation equation:

$$Y_{in} = \frac{1 + Z_{22} Y_l}{(Z_{11} Z_{22} - Z_{12} Z_{21}) Y_l + Z_{11}} \quad (5)$$

It is therefore recommended that the characteristics of side branch elements for acoustic filters as well as other discontinuities be measured and characterized this way, since it is very difficult to measure the shunt admittance presented by these elements at the pipe wall. The transmission loss or sound pressure level differences between two points in a system require input admittance calculations:

$$TL = -20 \log \frac{2}{|1 + Y_l/Y_o|} \left( \frac{\text{Re } Y_l}{Y_o} \right)^{1/2}$$

$$\left| \frac{P_o}{P_l} \right| \text{ (dB)} = 20 \log \left( \frac{\text{Re } Y_l}{\text{Re } Y_o} \right)^{1/2}$$

To calculate the input admittance of a system as required above, one starts from the termination,  $Y_l$  or  $Y_o$ , and proceeds through the filter elements, other discontinuities, and lengths of system piping. The admittance is transformed by each section to finally present a value,  $Y_{in}$ , at the input. Only two equations are required for these calculations: Equation (5) above can be used to calculate the input admittance of any discontinuity or side branch element in terms of its termination and the transmission line transformation equation,

$$Y_{in} = Y_o \left[ \frac{Y_l + jY_o \tan 2\pi l_1 f/v_1}{Y_o + jY_l \tan 2\pi l_1 f/v_1} \right],$$

<sup>4</sup>E. L. Hixson, J. V. Kahlbau, and D. G. Galloway, "Guide to the Selection of Acoustic Filters for Liquid-Filled Systems," Defense Research Laboratory Acoustical Report No. 202 (September, 1962)

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can be used for lengths of pipe and expansion chambers. Here  $Y_0$ ,  $l$ , and  $v_1$  are characteristic of the section considered.

Any branching of the liquid flow in a piping system by a "tee" or manifold will also divide the acoustic energy. The division will depend on characteristics of the manifold and the impedance presented at each port. This situation can be analyzed by considering the device an n-port element. Again, sets of equations involving measurable parameters can be written:

$$\begin{aligned}P_1 &= Z_{11} \bar{V}_1 + Z_{12} \bar{V}_2 + Z_{13} \bar{V}_3 + \dots \\P_2 &= Z_{21} \bar{V}_1 + Z_{22} \bar{V}_2 + Z_{23} \bar{V}_3 + \dots \\P_3 &= Z_{31} \bar{V}_1 + Z_{32} \bar{V}_2 + Z_{33} \bar{V}_3 + \dots \\&\dots \\&\dots\end{aligned}\tag{6}$$

or, in compact matrix form,

$$\begin{bmatrix} P_i \end{bmatrix} = \begin{bmatrix} Z_{ij} \end{bmatrix} \begin{bmatrix} \bar{V}_j \end{bmatrix} \tag{6a}$$

The subscripts refer to each port. The impedance parameters are the input impedance  $Z_{ii}$  ( $i = j$ ) at each port measured with all other ports blocked, and the transfer impedance  $Z_{ij}$  ( $i \neq j$ ) between each port and all other ports with all other ports blocked. When each port is terminated in some impedance, the input admittance and pressure transfer ratio to each port can be calculated.

To illustrate, consider a "tee" with ports 1, 2, and 3. Port 1 has an acoustic pressure  $P_1$ , port 2 is terminated in  $Z_2$ , and port 3 is terminated in

$Z_3$ . Equations 6 become

$$P_1 = Z_{11} \bar{V}_1 + Z_{12} \bar{V}_2 + Z_{13} \bar{V}_3$$

$$0 = Z_{21} \bar{V}_1 + (Z_{22} + Z_2) \bar{V}_2 + Z_{23} \bar{V}_3$$

$$0 = Z_{31} \bar{V}_1 + Z_{32} \bar{V}_2 + (Z_{33} + Z_3) \bar{V}_3$$

where  $P_2 = -Z_2 \bar{V}_2$  and  $P_3 = -Z_3 \bar{V}_3$ . The input admittance is then

$$Y_{in} = \frac{\bar{V}_1}{P_1} = \frac{\begin{vmatrix} (Z_{22} + Z_2) & Z_{23} \\ Z_{32} & (Z_{33} + Z_3) \end{vmatrix}}{\Delta}$$

where  $\Delta$  is the determinant of the  $Z$ 's. It should be noted here that input admittance depends on the termination of both ports 2 and 3.

The ratio of  $P_2$  to  $P_1$  is then

$$\frac{P_2}{P_1} = \frac{+Z_2 \begin{vmatrix} Z_{21} & Z_{23} \\ Z_{31} & (Z_{33} + Z_3) \end{vmatrix}}{\Delta}$$

and the ratio of  $P_3$  to  $P_1$

$$\frac{P_3}{P_1} = \frac{-Z_3 \begin{vmatrix} Z_{21} & (Z_{22} + Z_2) \\ Z_{31} & Z_{32} \end{vmatrix}}{\Delta}$$

It is evident that a multiport device will require many impedance measurements and tedious calculations. However, these methods become practical

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with the impedance computer-plotter presently under construction and the availability of high speed computers programmed to handle matrix operations.

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